

SUPPORT OF LUNAR LASER RANGING SYSTEM IN AUSTRALIA

Grant NGR 09-015-208

Progress Report No. 2

For the period 1 July 1973 to 30 June 1975

Principal Investigator

Dr. Michael R. Pearlman

November 1975

Prepared For

National Aeronautics and Space Administration
Washington, D. C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138



The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
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SUPPORT OF LUNAR LASER RANGING SYSTEM IN AUSTRALIA

Progress Report No. 2

1. INTRODUCTION

Under this grant, the Smithsonian Astrophysical Observatory (SAO) is to assist Australia's National Mapping Agency (NATMAP) in establishing and operating the Air Force Cambridge Research Laboratory's (AFCRL) lunar laser ranging (LLR) system in Australia. The system was obtained by SAO as government-furnished equipment under a contract with AFCRL. The initial contract has been renewed for a 5-year period, ending 31 October 1977. The system was shipped to Orroral Valley, near Canberra, Australian Capital Territory, where installation is currently in progress under the direction of Dr. Peter Morgan, Senior Surveyor, NATMAP. The facility is expected to be operational in early calendar year 1976.

2. AVAILABILITY OF THE SYSTEM

The lunar laser ranging system was obtained by SAO from AFCRL, Bedford, Massachusetts, as government-furnished equipment in November 1972, for the purpose of establishing a laser ranging facility in Australia for ranging to distant orbiting and lunar targets. Under terms of the contract with AFCRL, SAO is responsible, on a best-effort basis, for pursuing the establishment of a suitable observatory and for providing assistance in setting up a laser ranging program that will contribute ranging data for geophysical investigations being carried out in the United States, Australia, and elsewhere. The equipment was shipped to Australia in March 1973, where installation is currently in progress at Orroral Valley, Australian Capital Territory.

After initial consideration of sites at Mt. Stromlo and Siding Springs Observatories near Canberra, Orroral Valley was selected by NATMAP on the basis of its low atmospheric water-vapor content. (High water-vapor content in the atmosphere can be detrimental to lunar ranging.) In addition, since Orroral Valley is a NASA tracking-station location (STDN), extensive support facilities are available. The SAO laser system, formerly located in Olifantsfontein, South Africa, and the Baker-Nunn camera from Woomera, Australia, will also be installed at Orroral Valley in early 1976, creating a comprehensive space tracking facility and a unique opportunity for integrating lunar and satellite laser work as a tool for geophysical research.

2.1 Working-Level Agreement

After discussions concerning, among other issues, the ability of NATMAP to modify the LLR equipment, the long-term availability of the equipment, and the policy regarding the distribution of data, a Working Arrangement between SAO and NATMAP was signed by the respective parties in May 1975. This working-level agreement is pursuant to an agreement dated 1 March 1973 between the National Aeronautics and Space Administration (NASA) and NATMAP (Department of Minerals

and Energy), which established the basis of cooperation between SAO and NATMAP. The Working Arrangement, included in this report as Appendix A, enumerates the basic responsibilities of the two organizations for the establishment of the LLR in Australia.

2.2 Status of the LLR Facility

Work commenced on site development at Orroral Valley in late 1973; by January 1974, NATMAP was undertaking geological studies to determine the final location of the building. The laser electronics were assembled and tested in November, with some assistance from Mr. J. D. Williams of the Hawaii (Mt. Haleakala) lunar laser site, who was visiting Sydney at the time. At the same time, plans were developed by NATMAP for the computer, data link, and control and data-acquisition facilities ancillary to the installation and for resilvering the telescope mirror.

Concrete was poured for the piers and the ground floor in early spring 1974, and trial erection of the telescope began in March. The piers and first floor of the building were completed in late June, and the telescope was placed the following month. The Ash dome, which was received from the United States in July, was assembled and installed in August, and a grounding system was established that October. The building was completed and formally handed over to NATMAP on 15 November 1974, after minor problems with the Ash dome and several conferences with the design crew, building inspector, and contractor. Considerable cleaning of the building and site was then undertaken, along with preparation for installing the electronics and computer equipment. By late May 1975, all the LLR equipment had been removed from storage and put in final position on site.

During delays in building construction in late summer of 1974, the tracker was fully rebuilt and tested. Both the primary and the secondary telescope mirrors were realuminized at Mt. Stromlo. In addition, optically flat windows for a laser-triggered spark gap to chop the laser pulse to 2 nsec were constructed at Mt. Stromlo in September. Preparations for reassembly of the telescope were completed in December, and installation of the 60-inch telescope optical system

began in the first week of January 1975. A major problem was encountered in trying to lift the heavy components from ground level to the observing floor above; a trolley was constructed to carry the mirror. The right-ascension drive was fitted to the telescope and tested, and a replacement backplate for the telescope for Hartmann testing and other photographic work was received in April.

In May 1975, the 60-inch mirror was removed from storage, lifted to the observing floor, and installed in the telescope. A small closed-circuit television system was ordered to replace the finder telescope, as the configuration of the standard one substantially reduces the available declination range. During post-installation tests, the telescope optics were found to show a residual astigmatism, which could not be removed by adjusting the tilt of the secondary mirror. Poor weather hampered resolution of this problem during the reporting period, although a probable solution has since been obtained.

A contract for the procurement of a computer system (21 MX disk system) was placed with Hewlett Packard Co. After revisions to the contract were sent to the Australian District Contracts Board in February 1975, the computer system was received in June. Hardware tests are in progress, and software development continued throughout this period, with good progress being made on the lunar predictor and statistical packages.

During the first part of this year, discussions and design work were initiated on the proposed microwave link to the valley site, as part of an overall program to attain 1- μ sec timing accuracy with the United States Naval Observatory.

2.3 SAO Activities

During this period, SAO acted as the principal United States interface between various United States agencies and NATMAP. SAO provided NATMAP with advice, recommendations, and coordination in such areas as site development, building design, aircraft monitoring, systems engineering, and overall facilities integration. SAO also procured various items not available locally in Australia and obtained engineering documentation and equipment manuals needed by Dr. Morgan;

such items include specialized hardware for the mount in the building, special parts, electronic components (especially transistors and diodes), and a set of difficult-to-obtain telescopic assembly drawings from Astrometric. Many items were provided to NATMAP on an emergency basis, thus preventing schedule delays that would otherwise have ensued.

Further assistance of this nature is anticipated, including both procurement and equipment repair within the United States.

3. VISITS BY SAO AND NATMAP PERSONNEL

Dr. Morgan visited the United States in October 1974 to confer with AFCRL and SAO on the lunar laser project. It is expected that the Orroral Valley LLR will participate in a global lunar laser campaign scheduled for 1976 and that shortly thereafter an intercomparison of lunar and satellite ranging can be undertaken for system shakedown and technique evaluation. Both are extremely promising tools for high-accuracy measurements of crustal motion.

Dr. Michael R. Pearlman, Principal Investigator, visited the Orroral Valley site in January 1975, meeting with Dr. Morgan and the lunar ranging staff. The purpose of Dr. Pearlman's visit was to inspect the site, discuss the lunar ranging program, and investigate the feasibility of joint scientific undertakings, including the possible integration of lunar and satellite laser work as a tool for geophysical research.

4. FUTURE PLANS

The following are scheduled goals and future plans for the LLR project:

A. Throughout the performance of this grant, SAO will continue to provide logistics, technical, and systems recommendations and support in the establishment of a lunar laser ranging facility in Australia and will continue to serve as prime interface among NATMAP, NASA, and AFCRL on all matters related to the LLR facility.

B. SAO will continue to procure and provide equipment and supply items not available locally in Australia throughout the period of the grant.

C. An SAO laser engineer will visit the site in Australia in January 1976 to discuss laser operations with Dr. Morgan.

D. The lunar ranging facility in Orroral Valley will become operational in February 1976.

E. SAO will thereafter continue to act as interface among interested groups in the United States and Australia and will provide advice, recommendations, and operational and logistics support to NATMAP on a best-effort basis.

F. Dr. Pearlman will visit the site in April 1976 to inspect the facility, provide operational guidelines, and discuss joint scientific and technical projects.

5. NO-COST EXTENSION OF THE GRANT

Because of continued schedule delays and a change of emphasis in the type of direct support required of SAO, the grant has been extended at no cost until 31 March 1976. Following the scheduling outlined above (Section 4), SAO believes it can conclude the support required to assist the Australian agency in establishing an operating lunar ranging capability by that date within the scope of the funds allotted.

APPENDIX A

APPENDIX A

WORKING ARRANGEMENT
BETWEEN
THE SMITHSONIAN INSTITUTION ASTROPHYSICAL OBSERVATORY, U.S.A.
AND
THE DIVISION OF NATIONAL MAPPING, DEPARTMENT OF MINERALS
AND ENERGY, AUSTRALIA
FOR
THE INSTALLATION AND OPERATION OF LUNAR LASER
RANGING SYSTEM IN AUSTRALIA

Through the agreement dated March 1, 1973 the National Aeronautics and Space Administration of the United States of America (NASA) and the Division of National Mapping, Department of Minerals and Energy of Australia have established the basis of cooperation between the Smithsonian Institution Astrophysical Observatory (SAO) and the Division of National Mapping (NATMAP) for a laser ranging program. This agreement was entered into by both countries to promote the establishment and operation of a laser ranging system (System) in Australia. The System is to be used for ranging to lunar retroreflectors and high altitude satellite retroreflectors.

The working arrangements between SAO and NATMAP, enumerated below, set out the basic responsibilities of the two organisations for the establishment of the System in Australia.

Release of public information regarding this experiment may be made freely by each agency for its own portion of the experiment and, insofar as the participation of another agency is concerned, after suitable coordination.

Individual representatives of each organisation will be given all available support when at the other's facilities.

SAO will:

1. Provide, on loan, the System as described in Attachment 'A' hereto, entitled "List of U.S. Government Property Provided on Loan by SAO to NATMAP".
2. Act as the principal U.S. interface between NATMAP and NASA on all matters related to the scientific program and the laser ranging system, particular the selection of the site, the System's performance, the ranging operations, the observing program, and the distribution and exchange of data.
3. Provide technical assistance and consultation on the System hardware, and coordinate scientific activities relating to laser ranging.
4. Provide ranging predictions, offset guiding data and related information obtained from others, to support the laser ranging operations covered by this Working Arrangement.
5. Establish jointly with NATMAP the scientific programs and data handling procedures.

NATMAP will:

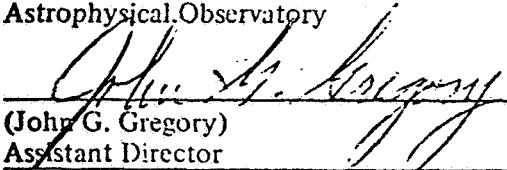
1. Assume the responsibility for the System listed in Attachment 'A' in accordance with the provisions of Attachment 'B' hereto entitled "Responsibilities for U.S. Government Property on Loan to NATMAP by SAO", including the cost of storage, transportation to the site and incidental costs thereto.
2. Provide and control a suitable site, facility, shelter, staff, services, logistic and maintenance support, and supplies to achieve and maintain the capability of ranging to lunar retroreflectors and high altitude satellite retroreflectors.

3. Prepare documentation, maintain records, and furnish copies thereof to SAO on matters dealing with:
 - a) ranging data;
 - b) maintenance or modifications which influence the interpretation of the data; and
 - c) alignment and operating procedures.
4. Make modifications to the System as deemed necessary to improve reliability or optimize the System for ranging to lunar retroreflectors and high altitude satellite retroreflectors, subject to conditions of a) and b) below:
 - a) Before making any major modifications which are irreversible such as redesign or restructuring of the System components which would inhibit or degrade the capability of the System for ranging to lunar or high altitude satellite retroreflectors, NATMAP will first submit copies of drawings and data that describe the modifications and obtain the written consent of SAO.
 - b) NATMAP may proceed with modifications other than those covered in a) above, but will send technical details of the changes to SAO, preferably before they are incorporated in the System.
5. Develop detailed operational schedules, which are in accord with programs agreed to by NATMAP and SAO.
6. Develop operational procedures for data acquisition, handling and distribution to meet the requirements of the scientific programs and furnish SAO with the data obtained.
7. Upon completion of the project, or termination of this Working Arrangement, disassemble the System, prepare it for shipment to the U.S. and transport it to the point of shipping from Australia; or, if agreeable to the parties concerned, accept ownership of all or part of the System through transfer of title or through abandonment. In neither case will SAO have an obligation to restore the site.

It is further agreed that there will be no exchange of funds between SAO and NATMAP. that each party hereto will bear the cost of discharging its respective responsibilities, and that any other matters not expressly agreed upon herein shall be resolved by mutual agreement using the intent and spirit of this Working Arrangement as a guide.


The Working Arrangement shall enter into force on the date on which it is signed and shall continue until October 1977, and shall be automatically renewed annually thereafter unless either party provides written notice to the other party of intention to terminate four months in advance of the desired termination date. However, the term of this Working Arrangement is contingent upon the continued availability of the System and lunar predictions to SAO, continuation of NASA support to SAO, the continuation of appropriated funds, and the continuation of the NASA-NATMAP agreement dated March 1, 1973.

For the Smithsonian Institution
Astrophysical Observatory


(John G. Gregory)
Assistant Director


(Date)

For the Division of National Mapping


(B.P. Lambert)
Director, National Mapping


(Date)

**LIST OF U.S. GOVERNMENT PROPERTY
PROVIDED ON LOAN BY SAO TO NATMAP**

- (1) Lunar Laser Ranging System consisting of the following components:
- (a) Cassegrain telescope system, including
 - 60-inch Cervit primary mirror
 - secondary mirror, beam splitter, finderscope
 - guide telescope mounting pedestal, supports, trusses, rings
 - plates, bearings, declination cube, bearings
 - motors and drives, counterweights.
 - (b) Main field guiding system, including
 - transfer optics, beam splitter
 - image dissector tube
 - electronic tracker control, console
 - mechanically driven offset stage
 - (c) Laser receiver control and equipment, including
 - housing box
 - laser control console
 - 5 pulse networks, charging power supply
 - 5 laser heads with rubies and flash tubes and spares
 - Q switch and controller
 - Pockels cell and spark gap chopper
 - photomultiplier, photodiode
 - tunable etalon filter
 - blocking filters and housing
 - (d) Data processing and control console
 - assorted nuclear instrumentation modules and bin
 - power supply
 - (e) Temperature controllers, gas regulator, still
 - piping cabling, lightning arrestor, electric line filter
 - (f) Meteorological recording equipment
 - (g) Optical alignment telescope and miscellaneous alignment parts and components, gas lasers, energy detectors, retroreflectors
 - (h) Miscellaneous tools, spare parts with cabinets and boxes
 - (i) Electronic equipment, including
 - oscilloscope with probes, plug-in units, cart, camera
 - power supplies, amplifiers, recorders
 - counters, oscillators, impedance bridges
 - multimeters, digital voltmeters
 - digital thermometer, electrometer.
 - programmer, laser firing, hardwired
 - loran aerial
 - Caesium beam time standard
- (2) Available software applicable to above items (a) through (i)

**RESPONSIBILITIES FOR U.S. GOVERNMENT PROPERTY
ON LOAN TO NATMAP BY SAO**

1. Government - Furnished Property. SAO shall furnish to NATMAP for use in connection with and under the terms of the Implementing Agreement the property described in Attachment 'A'; In the event the property is received by NATMAP damaged or in a condition not suitable for the intended use, NATMAP shall notify SAO of such fact.
2. Title. Title to all property loaned by SAO shall remain in the U.S. Government. Title shall not be affected by the incorporation or attachment thereof to any property not owned by the U.S. Government nor shall such property, or any part thereof, be or become a fixture or lose its identity as personality by reason of affixation to any realty.
3. Control. NATMAP will verify the property received against Attachment 'A', advise SAO of any discrepancies, or damage, and submit a written receipt listing all items of property received. NATMAP will once a year take physical inventory of the property and submit an appropriate report to SAO. SAO reserves the right to inspect the property at reasonable times.
4. Write - off. NATMAP will seek the advice and approval of SAO before disposing of any item in Attachment 'A' or others furnished by SAO.
5. Risk of Loss. Except as provided below, NATMAP shall not be liable for loss or destruction of or damage to the property furnished (Items in Attachment 'A' and any other furnished by SAO) if due to: fire, lightning, windstorm, cyclone, tornado, hail, explosion, riot, civil commotion, vandalism, malicious mischief, sabotage, smoke, earthquake, flood, hostile or warlike action; provided that NATMAP will be responsible for any loss or damage which results from willful misconduct or lack of good faith of any of the NATMAP managerial staff or failure on their part to properly maintain, repair and protect the property. Upon the happening of loss or damage to or destruction of and property furnished (as stated above), NATMAP shall notify SAO and furnish a statement of the property lost, damaged or destroyed and the time and origin thereof.
6. Liability. SAO, its officers, employees and agents shall not be held liable for any property damage or personal injury or death caused by or resulting from the property while in possession of NATMAP, unless it is demonstrated that such damage, injury or death are caused by willful misconduct or lack of good faith of any of the SAO managerial staff.
7. Final Accounting. Upon the completion of the agreement, NATMAP will submit an inventory schedule of all property loaned (see 4. above) for this program, showing its present condition.